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(14) ETL

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: R028	2. GOVT ACCESSION NO.: AD-A109 366	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Computer-Assisted Photo Interpretation Research at USAETL		5. TYPE OF REPORT & PERIOD COVERED: Paper
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): George E. Lukes		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Engineer Topographic Laboratories, Ft. Belvoir, VA 22060		12. REPORT DATE: 21 April 1981
		13. NUMBER OF PAGES: 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

AD A109366

DTIC FILE COPY

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

DTIC ELECTE JAN 7 1982 S D

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

computer-assisted photo interpretation research (CAPIR)
geographic information system (GIS)
stereo graphic superposition
Optical Bar Camera
cartographic feature extraction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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positioning, mensuration, stereoscopic area search, GIS creation and playback, and elevation data extraction. New capabilities under development include stereographic superposition, a digital image workstation, and integration of panoramic Optical Bar Camera photography as a primary GIS data source. This project has been conceived as an evolutionary approach to the digital cartographic feature extraction problem. As a working feature extraction system, the CAPIR laboratory can serve as a testbed for new concepts emerging from image understanding and knowledge-based systems research.

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Computer-assisted photo interpretation research at USAETL

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Abstract

A program in computer-assisted photo interpretation research (CAPIR) has been initiated at the U.S. Army Engineer Topographic Laboratories. In a new laboratory, a photo interpreter (PI) analyzing high-resolution, aerial photography interfaces directly to a digital computer and geographic information system (GIS). A modified analytical plotter enables the PI to transmit encoded three-dimensional spatial data from the stereomodel to the computer. Computer-generated graphics are displayed in the stereomodel for direct feedback of digital spatial data to the PI. Initial CAPIR capabilities include point positioning, mensuration, stereoscopic area search, GIS creation and playback, and elevation data extraction. New capabilities under development include stereo graphic superposition, a digital image workstation, and integration of panoramic Optical Bar Camera photography as a primary GIS data source. This project has been conceived as an evolutionary approach to the digital cartographic feature extraction problem. As a working feature extraction system, the CAPIR laboratory can serve as a testbed for new concepts emerging from image understanding and knowledge-based systems research.

Introduction

Cartographic maps, abstract representations of some portion of the world's surface, are fundamental to man's understanding of his environment. Ancient maps of the Babylonians, Egyptians and Chinese literally preceded the development of written language. Primitive cultures (Eskimos, American Indians and Marshall Islanders) developed maps to diagram the areas known to them. From early times to the present, man has developed maps and charts as functional spatial models of his world for exploration, trade, public administration, resource management and military affairs.

In the first half of this century, map making was dramatically transformed by the advent of aerial photography and the subsequent development of photogrammetry. These tools, which are far more accurate, rapid and economical than any known technique, have been universally adopted for large-area mapping. Now, in the second half of this century, another revolution is underway. This one has been inspired and fueled by the advent and success of the digital computer.

Digital technology creates opportunities for new data acquisition devices. Computerized systems support the derivation of elevation and planimetric data from imagery. Digital approaches are leading to improved processes for geographic data storage, management and exploitation. The driving force in the military mapping, charting and geodesy (MC&G) community, however, is the growing demand for digital cartographic products. Within the Department of Defense, the production of digital cartographic data already accounts for sixty per cent of the Defense Mapping Agency (DMA) labor force. Weapons systems supported by such digital data include the cruise missile, the Pershing II missile, Firefinder and various aircraft simulators with total area coverage requirements currently in excess of eighteen million square nautical miles (Nicholson, 1981).

The primary data source for these digital products is stereoscopic aerial photography acquired by modern mapping and reconnaissance cameras. With the notable exception of stereocorrelation equipment, extracting information from imagery is a labor-intensive, manual process conducted by specialists interpreting stereo aerial photography to produce intermediate manuscripts and associated data lists (Case, 1981). Manual digitization is used to convert manuscripts into machine-readable formats. Further processing is required to assemble, edit and check the derived data for production of specified digital products. Long-term data maintenance, update and quality control requirements are currently addressed using similar labor-intensive methods. It is obvious that a substantial gap exists between current manual image analysis procedures and the requirements to produce large volumes of digital cartographic data.

The U.S. Army Engineer Topographic Laboratories initiated a program in computer-assisted photo interpretation research (CAPIR) which addresses this problem. The central objective is to support the human specialist with hardware and software that will make information extraction from stereoscopic aerial photography that is simpler, faster and more accurate than existing manual photo interpretation procedures. The explicit intention of the program

is to impact on near-range and mid-range priority areas of DMA, and digital spatial data users, by developing and demonstrating improved procedures to produce, intensify, manage and exploit digital cartographic data files.

It is envisioned that the CAPIR program will be an evolutionary, interactive system used to support the integration and testing of selected image understanding and automated feature extraction techniques which may contribute directly to enhanced operational capabilities in the future.

This paper presents the initial concepts of the computer-assisted photo interpretation research program and then describes the laboratory CAPIR system recently configured at USAETL. Basic system capabilities, that include point positioning and mensuration, stereo search, geographic data file creation and maintenance, are outlined. The capability to exploit the unconventional panoramic Optical Bar Camera is presented. The final section deals with on-going system enhancements which will create opportunities for the introduction of computerized scene analysis techniques.

Basic concepts of computer-assisted photo interpretation research

The challenges of creating, maintaining and exploiting large cartographic data files will require considerable innovation to reconcile the desired, but mutually exclusive, goals of quantity and quality production with minimized cost. The initial CAPIR environment presumes the primary data source to be high resolution stereoscopic aerial photography, the decision maker to be a human specialist and the products to be spatially encoded information captured in digital cartographic data files. The basic objective is to provide an effective interface between aerial photography, the photo interpreter and the digital products in order to expedite information extraction within the context of a computer-assisted environment. The design of a research facility to pursue these goals was guided by three basic concepts: (1) direct data entry by the human specialist to digital files in an interactive system; (2) use of a computer-interfaced stereoscope to support on-line stereo digitization; and (3) direct stereomodel superposition of computer generated graphics to provide immediate feedback for on-line photo interpretation and playback of existing cartographic data files. Each of these concepts requires elaboration.

Direct data entry

In order to support creation of digital cartographic files, the concept of direct data entry requires an interactive digitizing system enabling the human analyst to encode and store spatial data (point, linear and areal features) in digital data files. In addition to data entry, such a system supports interactive prompting, option selection, graphic data display, editing and, to minimize the errors and blunders, extensive data validation procedures. A variety of commercial digitizing systems based on x-y digitizing tablets are now available to support encoding spatial data from a two-dimensional source such as a cartographic manuscript or orthophoto. While such systems entail considerable capital investment, they have proven to be cost-effective in production settings where error minimization is essential.

Computer-interfaced stereoscope

The computer-interfaced stereoscope is the direct data entry device for the photo interpreter operating in the stereomodel. Point, linear and areal features are entered directly as labeled entities in digital files in terms of three-dimensional ground coordinates (latitude, longitude, elevation). Recently, a family of photogrammetric instruments, termed analytical plotters, has become available which can perform this function (American Society of Photogrammetry, 1980). Based initially on embedded minicomputers, advanced analytical plotters now use microprocessors to perform real-time calculation of the ground coordinates associated with the position of a "floating dot" perceived in a stereomodel. Thus, the location of points or targets are determined; heights and distances are measured; streams of points are encoded to represent linear features and lines are connected to define areal features. The analytical plotter also serves to maintain the stereomodel during translation by automatically clearing y-parallax and can be programmed to automatically drive to selected locations in the stereomodel.

Stereomodel superposition of computer graphics

The analytical plotter has been implemented as an interactive photogrammetric system which transmits a stream of ground coordinate data to a host computer without provision for direct feedback of digitized data to the plotter operator viewing the stereomodel. These instruments can be considered to function as simple stereo digitizers. To pursue effective computer-assisted photo interpretation research, a feedback mechanism is required in which computer-generated graphics representing encoded data are displayed directly in the stereomodel. Rigorous projection of the graphics based on fundamental photogrammetric principles

is necessary to provide one-to-one correspondence with the photo coordinate system. The implications of this concept, termed superposition, are profound. In producing cartographic data files, superposition provides the real-time feedback of encoded data to the photo interpreter essential for on-line analysis. Efficient quality control, maintenance, revision and intensification of cartographic data files can be addressed through the display of existing digital data in suitable aerial photography. Fusion of spatial data from any source can be accomplished in the stereomodel exploiting a common ground coordinate system.

Software for an integrated system

The requirements for extensive software to support specialized hardware components is implicit within each of these concepts. A geographic information system is necassary to capture, organize and store the extracted spatial data. Specific modules are necessary to support the analytical plotter, graphic superposition and other components. Additional software is required to manipulate and exploit derived data to generate specific products which will range from traditional topographic maps and charts to special-purpose graphics, statistical summaries and synthesized reference scenes. Building on the foundation of a functioning data extraction system based on human control and decision making, substantive issues of computer-assisted decision making and automation of selected subtasks may be systematically investigated through the development of further software.

The computer-assisted photo interpretation research facility

A laboratory has been designed and recently installed at USAETL to support computer-assisted photo interpretation research studies. The initial CAPIR laboratory configuration supports two workstations in an interactive minicomputer environment providing baseline capabilities including a general-purpose geographic information system. Evolutionary development of the facility is anticipated including additional hardware, firmware and software.

Stereoscopic workstation

The stereoscopic workstation (Figure 1) represents the unique subsystem of the CAPIR facility which implements a real-time interface between a photo interpreter analyzing stereo aerial photography and a host computer with digital geographic files. The principal component of the workstation is an APPS-IV analytical plotter, modified to accommodate graphic superposition.

Figure 1. Stereoscopic workstation. A photo interpreter viewing high-resolution aerial photography with the APPS-IV analytical plotter is linked directly to the CAPIR system minicomputer. His right hand controls stereomodel translation using a trackball while the left hand adjusts an elevation wheel to control the "floating dot." The beamsplitter and CRT display for graphic superposition can be seen in the upper right.

Figure 2. Superposition Graphic Display. This photo, taken from the rear left corner of the instrument, shows a computer-generated overlay on the face of the custom 7" CRT. Use of photogrammetric projection to compute superposition graphics from ground coordinate data assures one-to-one correspondence of the overlay to the photo that accounts rigorously for photo scale, orientation and relief displacement.

The APPS-IV is a commercial, medium-accuracy, analytical plotter (Greve, 1980) exhibiting positional accuracies of less than ten micrometers RMSE. The existing optical system supports stereo viewing of photo transparencies or prints on dual 10" X 10" stages over a 7:1 zoom range of 2.3X to 16.1X with a resolution of 64 line pairs per millimeter at maximum resolution. Extensive, internal, microprocessor-based electronics perform real-time control functions which include: stage drive and loop-close for automated clearance of y-parallax; computation of coordinates to relate the position of the instrument floating dot to a three-dimensional, real-world ground coordinate system; and a buffered, asynchronous, serial (RS-232c) interface to a host computer. Used as a computer-interfaced stereoscope, the analytical plotter enables rigorous point positioning, mensuration and direct stereo digitization of point, linear and areal features.

The internal APPS-IV control firmware has been expanded to support on-line extraction of elevation data by profiling. In this mode, the operator specifies sampling parameters for a digital elevation model (DEM), then the instrument stages are driven under automated control with the operator using the elevation control to construct the profile. This capability will support limited production of DEM in the base plant and in the field (possibly in conjunction with editing operations) and will be used in specialized terrain analysis procedures.

The most profound extension of computer-assisted photo interpretation capabilities embodied in the initial facility configuration is the superposition of computer-generated graphics within the stereomodel (See Figure 2). Superposition is accomplished by replacing the initial mirror in the right channel of the APPS-IV optical train with a beamsplitter to superimpose the image from a high-performance 7" vector graphics display on the right member of the stereopair (Greve et al, 1981). To the photo interpreter, the effect of superimposed graphics is analogous to using a conventional mirror stereoscope and working with an overlay on the right photo of the stereomodel. Superposition provides a real-time electronic "grease-pencil" which immediately displays the results of stereodigitization to the operator viewing the stereomodel. Equally significant, superposition provides for display of previously created geographic information files. Without superposition, the APPS-IV is basically a stereodigitizer transmitting spatial data to a computer. With superposition, bidirectional communication of extracted spatial data is established between man and machine, creating unprecedented opportunities for computer-assisted photo interpretation.

The stereoscopic workstation is augmented with a conventional CRT display terminal for alphanumeric communication with the host minicomputer. An auxiliary refresh, vector-graphics display is used for real-time display of data being digitized and for editing of system-resident spatial data. A voice recognition unit is being integrated into the APPS-IV, so that the operator can communicate from the workstation to the host minicomputer while maintaining stereo vision.

Monoscopic workstation

The second workstation supports direct data entry from orthographic sources (Figure 3).

Figure 3. Monoscopic Workstation. A digital tablet is used to capture spatial data from orthographic sources such as map manuscripts or orthophotos. A special-purpose emulator reformats the serial data stream from the tablet to mimic the APPS-IV. This permits applications programs to be executed on the system minicomputer from either workstation.

This monoscopic workstation is based on a large x-y digital tablet to enable digitization of intermediate source materials including existing map sheets, registered map overlays and manuscripts, as well as direct interpretation of orthophotos. In addition, approximate ground coordinates for control points used in aerotriangulation are derived with sufficient accuracy to support terrain-related applications.

The central component of the monoscopic workstation is a commercial, 36" x 48" table-mounted, backlit, digital tablet. A special-purpose electronic circuit has been interposed between the RS-232c output of the digital tablet and the RS-232c port of the host minicomputer. Signals from the digital tablet are reformatted, buffered and transmitted to mimic APPS-IV generated signals. As a result of this approach, applications programs designed for the APPS-IV may be executed from either the stereoscopic or monoscopic workstation.

This workstation also includes a conventional CRT display terminal for alphanumeric communications and a graphics terminal for display of spatial data during digitization or editing. Voice recognition and voice synthesis modules are being integrated into the workstation to support investigations of more effective input/output techniques.

Minicomputer environment

The CAPIR facility is supported by a Data General Eclipse S/250 minicomputer with Integral Array Processor. Standard peripheral devices include 800 and 1600 bpi magnetic tape drives, a 192 megabyte disk, CRT display terminals, a system console and a printer. An electrostatic plotter has been ordered to provide high-speed hardcopy graphics and textual output.

The system operates under the Data General Advanced Operating System (AOS), providing a multi-user, multi-tasking environment. System libraries currently consist of the International Mathematical and Statistical Library (IMSL), high-level Array Processor Software (APS), and graphics routines for Calcomp, Imlac, Tektronix and Versatec devices. Supported compilers currently include Fortran V, Pascal and assembly language. System utilities will include line and screen editors, a document processor and a sort/merge package.

Geographic information system software

An initial CAPIR objective was to support direct data entry from either workstation to a general-purpose geographic information system. This has been accomplished by adapting two large computer programs: the Analytical Mapping System (AMS); and the Map Overlay and Statistics System (MOSS). Both programs were developed by the U.S. Fish and Wildlife Service to support the National Wetlands Inventory and to provide rapid environmental impact assessment technology. The AMS software (Pywell et al, 1980) provides three capabilities: aerotriangulation of source imagery; digitization for data base creation and editing; and data base management. MOSS supports spatial analysis of derived spatial data bases in an interactive environment.

An interactive aerotriangulation capability is used to compute the camera parameters for the aerial photos to be used in stereo digitization. Using ground control, derived from geodetic files or topographic map sheets, and photo coordinates measured on the APPS-IV, a rigorous bundle adjustment is used to solve for camera parameters of position and orientation for as many as ten frames. The operator is led through the triangulation procedure by a sequence of menus featuring capabilities for on-line data inspection and editing, analysis of triangulation results and process control.

Data base creation is performed from orthographic sources on the monoscopic workstation or directly from aerial photography on the stereoscopic workstation. The photo interpreter uses the floating dot as a cursor to delineate and code point, linear and areal features which are transformed in real-time to form ground coordinates required for data base entry. Concurrently, encoded spatial data is displayed on a separate graphics terminal and, optionally, in the APPS-IV stereomodel via superposition. Previously created data entries can be recalled, displayed and edited. Verification of all data base entries is performed on-line under control of the original operator while the source material is readily available to insure the creation of a logically and topologically valid data base.

A data base management system is used to store all camera data, triangulation results and the encoded spatial data. Simple on-line queries of the data base are supported. Hardcopy plots from the digital spatial data can be registered to standard topographic maps or selected user-specified formats.

MOSS is an interactive spatial analysis software system (Reed, 1979) which stores and operates on topologically valid geographic data files produced by AMS or some external source. Supported data types include points, lines, polygons, rasters, elevation points

and DEMs. Specified data base queries, windowing and selective map retrieval based on size or feature label criteria are supported as well as formulated combinatorial questions and complex Boolean retrieval on raster data. A routine for interpolation of elevation point samples to a regularly-spaced DEM grid format is available as well as polygon-to-raster conversion. Spatial operations include logical and arithmetic cell compositing, polygon overlay, zone generation around point, line and polygon features, slope and aspect calculation on DEM, and area, length, perimeter and frequency calculations.

Computer-assisted photo interpretation research system capabilities

In the preceding section, descriptions of various system modules implied many of the system capabilities. This section will highlight major capabilities in a more systematic manner. By necessity, the organization of this material is somewhat arbitrary since many functional capabilities are by design closely related.

Aerotriangulation

Camera parameters of position and orientation are required for stereo compilation by the CAPIR APPS-IV or any other stereo plotter. Historically, aerotriangulation has been performed on large, general-purpose computers at centralized map production centers. In certain circumstances, users can expect camera parameters to be supplied with stereo photo data sets, such as the DMA Point Positioning Data Base (PPDB). As the computational power of minicomputers has increased, computationally intensive operations such as local aerotriangulation have become feasible. As previously discussed, the operational AMS software on the CAPIR system supports a ten-photo block adjustment program for the triangulation of frame aerial photography. In many respects, this program is an adaptation of a batch-oriented triangulation program augmented with an interactive editor, which permits efficient entry, display and modification of the required photogrammetric input data and inspection of results. Both metric and non-metric (i.e. Hasselblad 500EL) cameras are being triangulated successfully with this software.

Recently, a new single-model triangulation program has been developed for the panoramic Optical Bar Camera (Jackson et al, 1981). This is also an interactive program using APPS-IV photo measurements with externally derived geodetic control data to compute camera parameters for this dynamic reconnaissance camera. In addition, feasibility studies for stereo compilation of radar imagery have resulted in definition of a single-model procedure for synthetic aperture radar systems.

Point positioning and mensuration

Using data-based camera parameters, a stereomodel may be set up on the APPS-IV in a few minutes. The instrument loop-close option provides automatic clearance of y-parallax to maintain stereo vision throughout the model, and a precomputed checkpoint is measured to verify proper set-up. For any point in the stereomodel specified by the operator-controlled floating dot, ground coordinates are computed within 8.5 milliseconds. The CAPIR system employs a geographic coordinate system (longitude, latitude and elevation), although real-time conversion to some other representation such as Universal Transverse Mercator (UTM) or a state-plane coordinate system, is straight-forward.

Obviously, measurement of two points in the stereomodel enables rigorous mensuration of objects in terms of height, width and length, or the computation of distance between points. The military uses this point positioning approach for various targeting and navigation purposes. APPS-1 and APPS-IV instruments are currently being used with PPDB materials by the U.S. Air Force, Army, Marine Corps and Navy. Numerous civil applications exist for both point positioning and mensuration operations.

Stereoscopic search

Numerous requirements exist for broad area search of mapping and reconnaissance photography, including those characterized as object detection by Roberts (1981) in these proceedings. Using APPS-IV in loop-close mode, the stereomodel is automatically maintained while either the operator or the computer drives the instrument stages based on a predefined area search strategy. It is feasible to maintain and display a spatial record of the search-in-progress (total area to be searched, area completed, objects detected, etc.). When an object is detected, point positioning and mensuration functions may be invoked to assist object identification and to support direct entry of the interpreted data to a digital data base.

Stereoscopic data base creation

It should be apparent that creation of high quality spatial data bases from high resolution stereo imagery was a primary CAPIR objective which resulted in the integration of an

analytical plotter, graphic superposition and AMS software to form the stereoscopic workstation. This approach entails a significant capital investment, yet the benefits are profound: (1) high metric accuracy can be obtained through the use of rigorous photogrammetric procedures; (2) probability for error is minimized by eliminating intermediate products, performing on-line validation of feature codes and implementing data base verification with provision for error correction by the primary analyst using the original source materials; and (3) professional responsibility and accountability is assigned to the analyst who is supported by the tools necessary for competent performance. In a real sense, this computer-assisted photo interpretation approach represents an opportunity to evolve from an assembly-line approach to digital planimetric feature extraction to new procedures based on the practice of skilled cartographic craft by competent photo analysts.

Data base playback via superposition

Application of rigorous photogrammetric principles to implement graphic superposition supports not only real-time stereomodel display of spatial data as digitized, but also provides for the playback of existing digital spatial data in an arbitrary stereomodel. Just as real-time display opens the door to on-line photo interpretation, data base playback enables development of systematic procedures for quality control, revision and intensification of extracted data as well as opportunities for multi-source data fusion.

Mechanisms for the inspection and verification of encoded spatial data both in the base plant and in the field are essential for the production and acceptance of high quality digital cartographic products. Superposition playback displays extracted spatial data against the most detailed model of the real world available - the stereoscopic photo model. Source photography or some other stereomodel may be used as the photo base as the situation warrants. For users requiring the integration of data from multiple and/or external sources, the controlled stereomodel represents the unique option to create a universal frame of reference for display and merging of diverse spatial data.

Superposition playback can support an integrated approach to revision of cartographic data bases in which existing digital data is displayed in more recent aerial photography. Currently, limited editing routines embodied in AMS software can support rigorous digital map revision studies. The integration of sophisticated, interactive editing procedures will be required in order to develop an optimized capability.

Economic constraints and priority requirements will preclude base plant operations, such as the Defense Mapping Agency and the U.S. Geological Survey, from significant production of custom products to meet specific user requirements. In many applications, successful use of centrally produced digital cartographic data will require user intensification of the data base in order to incorporate additional detail within standard data classes, or user augmentation of standard products with additional classes of data. Further, some critical users will require a rapid response which will mandate a local intensification capability. Superposition with suitable editing software can directly impact on these problems.

Each of the capabilities just presented is predicated on the playback of existing cartographic data, but the generality of the CAPIR implementation enables playback of any data described by (X, Y, Z) coordinates. The problem of monitoring targets described by Roberts (1981) can be addressed by automatically driving a high-resolution stereomodel to the calculated target location, then superimposing existing target-related graphics. Military situation graphics or data collected from ground and electronic intelligence systems may be displayed in the stereomodel in a similar fashion providing novel opportunities for multi-source data fusion.

Elevation data extraction

In the most basic mode, the APPS-IV produces elevation data for operator-specified points in the stereomodel. This point data capture capability had been generalized with microprocessor firmware to support an elevation profiling procedure in which the instrument stages are driven along a program specified grid lattice automatically sampling elevations while the operator is responsible for maintaining the floating dot on the surface of the stereomodel. The AMS software is being extended to support storage, display and editing of DEM, as well as DEM collection using this option.

A dynamic camera model: the panoramic optical bar camera

The APPS-IV analytical plotter operates under a highly generalized microprocessor control system which is capable of supporting a range of dynamic (differentially projective) camera systems in addition to conventional frame mapping cameras. Recently, a model for the panoramic Optical Bar Camera (OBC) was developed on the CAPIR system (Jackson et al., 1981). This sophisticated reconnaissance camera (Figure 4) was used in the Apollo lunar mapping program to obtain high resolution, large-area photo coverage. The unconventional design

incorporates a long, folded focal-length optical assembly that constantly rotates about a central spin axis. In the case of the 24-inch focal length KA-80A OBC, this results in the exposure of individual frames measuring approximately 5" x 50" with variable scale as a function of scan angle.

Figure 4. ITEK Optical Bar Camera (OBC). The OBC is a sophisticated panoramic reconnaissance system providing high-resolution, wide-area photo coverage in either monoscopic or stereoscopic modes. APPS-IV firmware has been designed to support such dynamic camera models. AMS software is being expanded to accommodate OBC compilation, profiling and superposition.

Exploitation of panoramic imagery has been a mainstay of the military reconnaissance community. Recently, use of the OBC for civil applications has been studied using imagery obtained from high-altitude NASA aircraft (Weber, 1979). The unconventional geometry and formats, however, present serious obstacles to stereoscopic analysis, mensuration, and compilation.

CAPIR system support for the analysis of stereo segments of OBC imagery currently includes loop-close for stereo maintenance throughout the model, real-time computation of ground coordinates and a rigorous mensuration capability. The AMS software is being expanded to incorporate OBC source materials. As with stereo analysis of frame imagery, the extensive real-time photogrammetric operations remain essentially transparent to the photo interpreter.

Evolution of computer-assisted photo interpretation research

The CAPIR project envisions an evolutionary laboratory system based on enhancement and augmentation of existing hardware and software. For example, new optics designed for the APPS-IV have been optimized for superposition graphics which also provide significantly higher resolution and increased optical efficiency. Numerous enhancements to AMS and MOSS software are underway as well as a conversion of these programs to the DEC RSX-11M operating system. Two new efforts now underway will significantly extend CAPIR capabilities: stereo superposition; and a digital image workstation. A third area, knowledge-based system software, is receiving detailed consideration.

Stereo workstation

Superposition of stereo graphics, which will be independent of the stereomodel images, is being implemented as a modification of the stereoscopic workstation. The current single channel graphic display is being replicated and introduced into the second optical channel of the existing APPS-IV. The general photogrammetric approach used in basic superposition extends naturally to support the stereo case. Stereo superposition will enable display of digital elevation data for use with editing and profiling software, as well as novel three-dimensional graphic displays including line-of-sight and flight simulation.

Digital image workstation

A third CAPIR workstation is being developed to support stereo analysis of digital

imagery. Initially, a multi-channel video processor, driving a high performance stereo viewer, will be adapted and programmed to emulate the APPS-IV. Integration of these devices to the AMS and MOSS software will lead to the development of a new digital image work-station. This will enable computer-assisted photo interpretation of digital image data, support advanced point positioning studies and lead to stereo display of synthetic images that include shaded relief models from DEM and perspective terrain scenes. Later, solid-state cameras will be introduced into the APPS-IV optical train to support semi-automated pattern recognition studies. The goal is to develop techniques that enable the gradual transfer of selected decision-making responsibilities from the photo interpreter to the computer. This represents an open-ended opportunity for the introduction and evaluation of image understanding concepts in a highly interactive, stereoscopic, photo interpretation research environment.

Knowledge-based systems

In the last several years, research in the artificial intelligence community has resulted in a number of interesting computer programs that have come to be known as knowledge-based systems (KBS) (Barrow, 1979; NIH, 1980). Working as computer consultants in specific problem domains, these programs have demonstrated levels of performance that approach, and in some cases equal or exceed, the skill of expert humans. In a recent study, Duda and Garvey (1980) examined the potential KBS application to selected photo interpretation tasks. Their recommendations included the integration of KBS modules into the CAPIR system to support training, consultation, system monitoring and the evolution of autonomous photo interpretation assistants to aid the human analyst.

Summary

Considerable progress has been made in configuring a laboratory system dedicated to computer-assisted photo interpretation research. The initial goal of developing an interactive workstation interfacing a photo interpreter analyzing high-resolution stereoscopic aerial photography to a geographic information system has been realized. In less than a year, demonstration of current capabilities has impacted on funded developments for several Army and DMA projects. Additional application's studies are underway in each of the USAETL development laboratories and several interagency studies have been initiated.

At this time, the strength of the CAPIR system lies in the stereoscopic workstation enabling exploitation of hardcopy imagery by a skilled photo interpreter with direct linkage to a general-purpose geographic information system (GIS). An analytical plotter supports rigorous, real-time transformation of spatial data from a stereomodel to the GIS, and superposition provides for display of spatial data from the GIS in the stereomodel. Capabilities for rigorous point positioning, mensuration and profiling complement the basic capability for capturing, managing and exploiting spatial data in a GIS. The GIS software, which now supports conventional frame photography, is being enhanced to accommodate the panoramic Optical Bar Camera.

Currently, the major deficiency in the CAPIR system is the inability to readily incorporate significant software emerging from the artificial intelligence community for image understanding and knowledge-based systems. There is much to be gained by integrating the effective man-machine interface and geographic data bases embodied in the existing CAPIR environment with new artificial intelligence software for scene analysis and expert systems. Linkage to an advanced research system such as the ARPA/DMA Image Understanding Testbed (Fishler and Hanson, 1981), now being developed at SRI International, would provide significant opportunities to pursue new avenues of computer-assistance for photo interpretation of hardcopy photography as well as digital imagery.

CAPIR technology will impact upon base plant and field exploitation of hardcopy imagery in the military mapping community, although it is far too early to predict the nature and extent of the impact. This is an open-ended technology. The initial capabilities for rigorous geometric transformations between aerial photography and a GIS form a foundation that can support the development of additional computer-assisted techniques. The CAPIR approach presents a new opportunity to implement an evolutionary strategy. New modules from the research community can be tested, evaluated and, where successful, integrated into a working feature extraction system.

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Fig 1

Fig 2

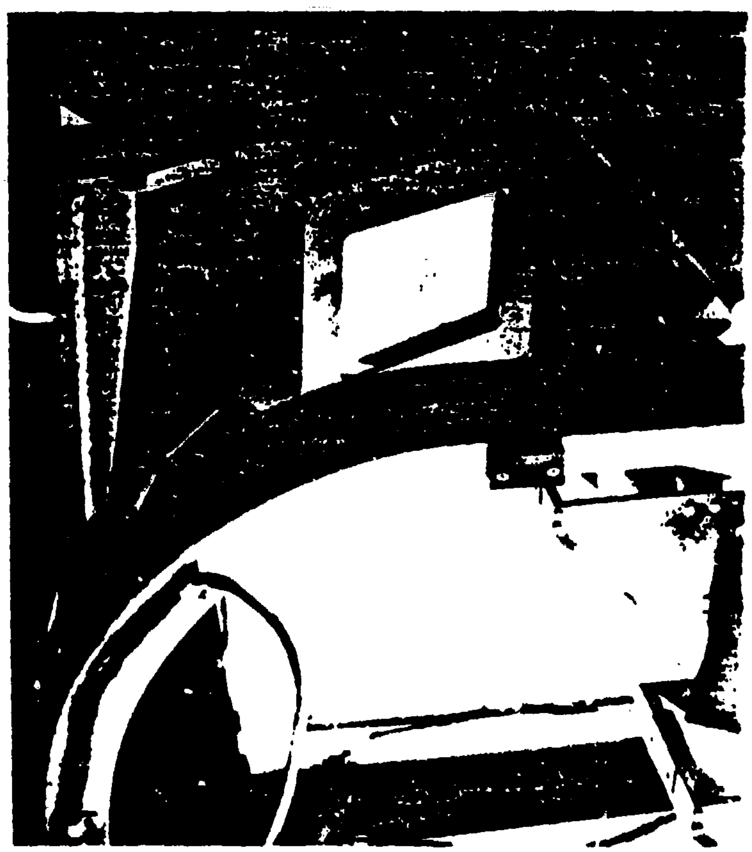
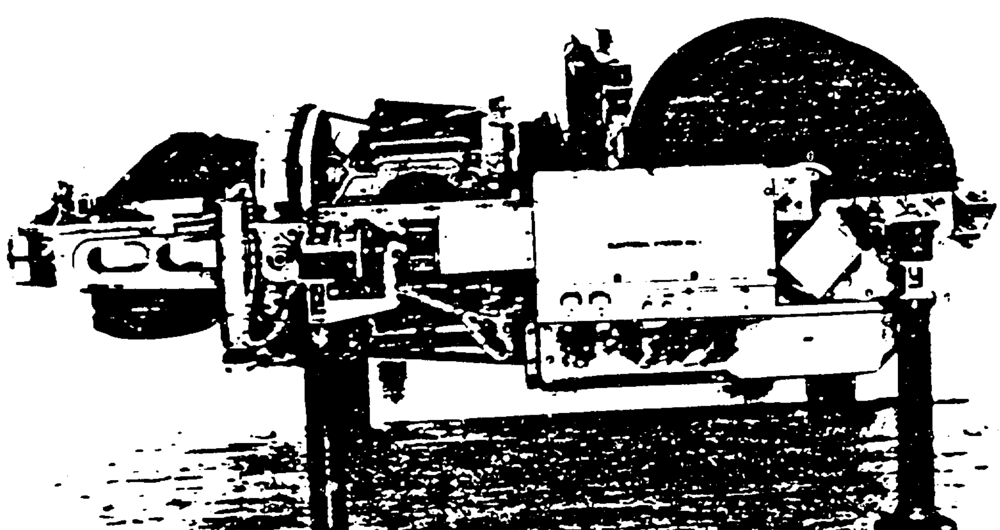


Fig 3

Fig 4



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